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LA-UR--84-1277

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CONF-840525--19

TITLE: OPERATIONAL PARAMETERS OF A 2.0-MeV RFQ LINAC

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SUBMITTED TO: The 1984 Linear Accelerator Conference, May 7-11, 1984
Darmstadt, Fed. Rep. of Germany

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OPERATIONAL PARAMETERS OF A 2.0-MeV RFQ LINAC*

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Summary

After extensive upgrading, our radio-frequency quadrupole (RFQ) linac is again installed on the accelerator test stand (ATS). The measured parameters of the RFQ, such as the output transverse emittance, transmitted beam, average energy, and energy spread is presented.

Introduction

In table I we show the design parameters of our RFQ. We made extensive experimental and theoretical studies[1] on our first version (RFQ1). In these studies we showed that RFQ vane voltage has a sensitivity to alignment errors that includes a scaling factor equal to $(L/\lambda)^2$, where L is the RFQ length and λ is the electric wavelength. Because of the long length of our RFQ, we reduced the machining tolerances on the vanes of our second version, RFQ2. In addition, seven dipole shorting rings were installed, which moved the dipole passband from 4 MHz below the quadrupole mode to 30 MHz above the quadrupole mode. The rings were installed with alternate horizontal and vertical shorts and have eliminated the dipole mode problem. The longitudinal-field tuning was obtained with a modest amount of vane shimming and with a new type of end tuner.[2] At low power, the measured "Q" of RFQ2 was 6600 or 67% of the theoretical value that was found using an RFQ model with no shorting rings. At full power, the Q value rose to 7500. We also improved the manifold and RFQ coupling. We calculated that 78% of the power is in the RFQ; the remaining 22% is in the manifold.

Our new source and accelerating column[3] supplied a low emittance, 100-keV H^- beam to a low-energy beam-transport section (LEBT), see fig. 1. Because we observed large emittance growth in transport lines in excess of one meter, we made the LEBT as short as possible by using permanent-magnet quadrupoles (PMQs) exclusively to match the beam to the RFQ. The program TRACE[4] was used to model the 20-keV region, the column, and the LEBT, and to match the 100-keV beam to the RFQ

TABLE I

ATS RFQ DESIGN PARAMETERS

Frequency	413 MHz
Ion	H^-
Number of cells	356
Length	289.23 cm
Vane voltage	111.34 kV
Average radius, r_0	0.394 cm
Final radius, a_f	0.270 cm
Final modulation, m_f	1.830
Initial synchronous phase, ϕ_f	-90°
Final synchronous phase, ϕ_f	-30°
Peak surface field	41.4 MV/m (2.06 Kilpatrick)
Nominal current limit	167 mA
Nominal acceptance at 100 mA	0.232π cm•mrad (normalized)

*Work supported by the US Department of Defense, Defense Advanced Research Projects Agency, and Ballistic Missile Defense Advanced Technology Center.

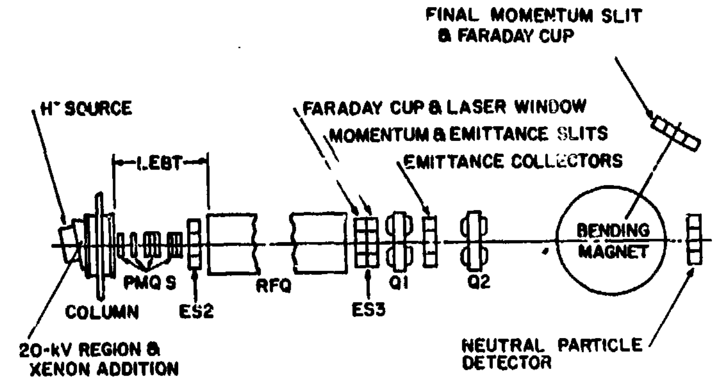

Fig. 1. ATS experimental setup.

input requirements. Using a miniaturized, electric-sweep emittance scanner,[5] we obtained good agreement between TRACE predictions and measured emittances at ES2 located 10 cm upstream of the RFQ match point. By varying the amount of neutralizing xenon injected into the 20-keV region, we were able to change both the emittance area and shape at ES2. We were unable to obtain a perfect beam match to the RFQ with the limited space and fixed-strength PMQs in the LEBT. However, because the RFQ acceptance is greater than the beam emittance, substantial transmission rates were predicted using PARMTEQ, even with poor matches. The typical input beam current at the RFQ entrance was 100 mA, and typical, normalized rms emittance areas in the x- and y-planes were 0.013 and 0.022π cm•mrad, respectively.

Output Beam Diagnostics

We measured the total transmitted beam with a wide-band pulse-current transformer. The transverse emittance was measured with an automated slit-and-sandwich collector (ES3) positioned 7 cm from the exit of the RFQ. We measured the beam momentum with a focusing spectrometer that consisted of two quadrupoles, used primarily for vertical containment, and a horizontal 60° bending magnet with circular pole tips. We calibrated the spectrometer with a low-energy xenon beam whose momentum equaled that of the expected 2.0-MeV H^- final beam. The momentum resolution was 0.1%, and the absolute accuracy of the spectrometer was within 0.16% of the predictions based on a POISSON model of the bending magnet and a TRACE model of the spectrometer.

Results

The RFQ reached full power after a conditioning period of about 150 hours. During conditioning the RFQ had fewer spark downs when beam was present in the structure. A plot of the transmission, both measured and predicted with PARMTEQ, versus rf vane voltage is shown in fig. 2. We determined the vane voltage V in the RFQ by setting

$$V = S \times P^{1/2} \quad , \tag{1}$$

where P is the power as determined from the pickup loop in the RFQ. The scale factor S was determined by using eq. (1) and the measured value of P and the predicted value of V that occurred when the RFQ transmitted half of the maximum possible current. The maximum transmission was 60 mA for 100-mA injected beam and was

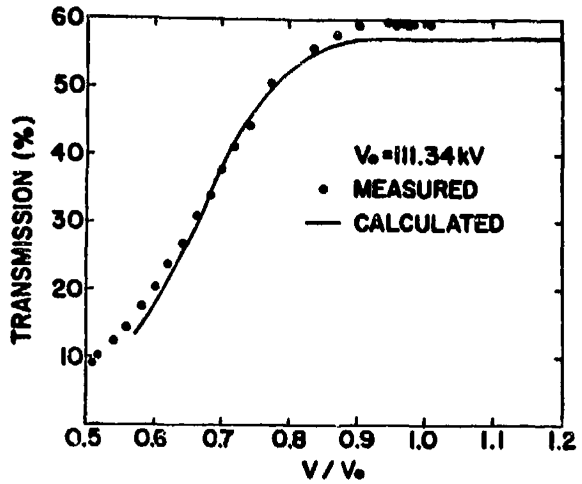

Fig. 2. Measured and predicted transmission versus vane voltage.

slightly larger than the 57 mA predicted by running the measured input beam emittance through the PARMTEQ model of our RFQ. If the beam were perfectly matched to the RFQ, we would expect 90 mA to be transmitted. By empirically adjusting both the xenon flow into the 20-keV region and extractor voltage, we increased the transmitted current to 75 mA out of 106 mA injected into the RFQ. Tests showed that this increase was not the result of adjusting the input beam energy but was the result of better matching the beam emittance to the RFQ acceptance. Recent TRACE computer studies showed even better matches can be obtained, resulting in better transmission, by repositioning the PMQs in the LEBT.

In fig. 3a and b, we show the observed and predicted energy spectra for various vane voltages. At designed power, the accelerated beam had no low-energy component and had the predicted energy of 2.0 MeV. The measured FWHM was 1.3% and compared well with the predicted value of 1.2%.

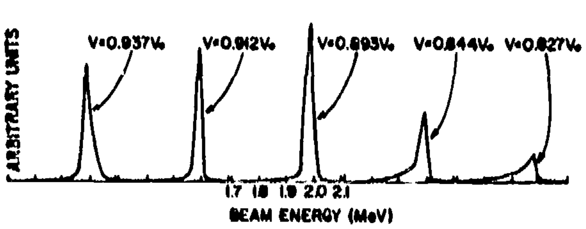

Fig. 3a. Measured beam energy spectra for various vane voltages.

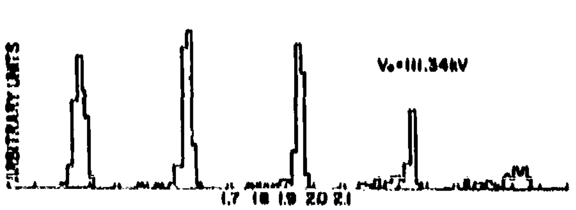

Fig. 3b. Beam energy spectra, predicted by PARMTEQ, versus various vane voltages.

Because the horizontal emittance slits at ES4 were severely eroded during the spectrometer measurements, no reliable horizontal emittance values could be obtained. Preliminary results indicate that the normalized rms emittance in the vertical plane was between 0.02 and 0.03π cm•mrad.

Conclusions

We have successfully operated the longest RFQ (measured in normalized units L/λ) with an accelerated H^- beam having the highest power ever obtained with such a structure. The transmission and energy measurements of our RFQ beam are in good agreement with the PARMTEQ predictions. By rearranging the PMQs in the LEBT, we expect to improve the beam matching to the RFQ and, thereby, increase the transmission. Because of the high power density of our RFQ beam, we must modify the present slit-and-collector method or replace it with nonintercepting methods to measure the transverse emittance.

Acknowledgments

We wish to express our thanks to Martin L. Milder for his assistance in the installation of much of the ATS hardware, and to E. Alan Wadlinger for his assistance in the PARMTEQ studies.

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